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Quantitative Characteristics of the Conducting System in Stem of Winter Wheat Genotypes with Spike Fertility Genes

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Abstract. Three groups of winter wheat (*Triticum aestivum* L.) genotypes having spike fertility genes (SFG) were used in field trials: (1) Tetrastichon sessile spikelets (TSS), (2) Normal spikelets (NS), (3) Indeterminate rachilla spikelets (IRS). The capacity of conducting system of the peduncle and the ear sink capacity of the main stem have been measured. There was a highly significant positive correlation ($r = 0.899$ and higher) between peduncle diameter and parameters quantifying peduncle vascular system. Compared with the control cultivar Hana, the TSS and NSS genotypes had higher both the number of vascular bundles, phloem and bundle cross section area and kernel number per ear. However, the highest kernel number per ear was found in the IRS genotypes although their bundle and phloem area was only equal or even lower then that of the variety Hana. Further studies are needed in developmental anatomy of spikes and stems to elucidate also differences in the relationships between the conducting capacity and kernel number per spikes in the TSS, NS and IRS genotypes.

Compared with the older cultivars, the ears of the contemporaneous ones are characterized by a higher number of kernels per spike. Such an increase has been achieved by the use of dwarfing genes Rht 1 and Rht 2, which induce the plant insensitivity to giberellin and consequently shorten the stem. Simultaneously, an increase in the accumulation potential of the ear takes place. The main effect of the Rht genes on yield consists in an increase in the number of kernel per spikelet (Brandle and Knott 1986).

The use of spike fertility genes offers another way for the potential increase in the kernel number per ear. These genes are thought to directly control the spike morphology and structure. According to Smoček (1987), the expressions of only three genes have been studied most frequently, namely (1) Ts gene that induces the formation of higher number of sessile spikelets on one spike rachis node which is manifested in the tetrastichon ear type, (2) a common effect of Rm and Ts genes that induce the formation of longer rachilla internode and

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finally (3) N-normaliser gene which produces a spike of a normal type. However, genetic system of spike fertility genes has not yet been fully described and understood. While Pennelt and Halloran (1984) divided fertility genes into 3 groups according to ear type, Smoček (1987) described 6 groups. We use the Smoček's description and for experiments reported in this paper the genotypes from the following 3 groups have been taken:

1. TSS-Tetrastichon sessile spikelets: two to three horizontaly placed spikelets on one spike rachis node represent the typical feature of this group.
2. NS-Normal spikelets: the spike type is normal with just one spikelet on the spike rachis node but with a higher number of nodes on the spike rachis or a higher number of kernels per spikelet.
3. IRS-Indeterminate rachilla spikelets: characterized by longer rachilla of some spikelets which results is a ramification on some spike rachis nodes.

Genotypes of the all three groups produce an increased sink capacity because of an increased number of spikelets and kernels per ear. However, the use of such a higher sink for achieving a higher kernel production per ear supposes not only a high assimilate production but also a sufficiant conducting system capacity (Lupton 1972, Nátrová 1987). This paper describes a quantitative analysis of the conducting system and its comparison with ear sink capacity in some genotypes of the above described groups of winter wheat.

MATERIAL AND METHODS

Five and seven genotypes of winter wheat (*T. aestivum* L.) were used in field experiments grown in 1988 and 1989, respectively. The genotypes represent types of the ear structure of the TSS, NS and IRS groups.

The following genotypes were used (the letters describe the gene group while the number specifies our internal denomination): in 1988 – TSS 2, TSS 16, NS 24, IRS 20, IRS 21, in 1989 – TSS 2, TSS 16, TSS 37, NS 45, NS 46, IRS 20, IRS 21. The seed was kindly supplied by Ing. J. Smoček DrSc. from the Cereal Research and Breeding Institute in Kroměříž. As a control the standard cultivar Hana has been chosen. The viable seed rate was 4.5 milions of kernels ha^{-1}.

At maturity, 1 cm below the ear, about 1 cm of the internode has been cut off from the peduncle of the main stem from 20 plants and placed into boiling water for one hour and subsequently into glycerol for weakening the tissue. Hand made cuts were used for measuring the stem diameter, the number of big vascular bundles and the cross section area of phloem and of the whole bundles by using a microscope WILD M5A with a cammera and monitor (Wild Heerbrugg/Switzerland). The bundle and phloem size have been drawn from the monitor on a transparency and the area measured by a planimeter. The same stems were used for measuring parameters of the ear structure, *i.e.* the number of both main and secondary spikelets and the number of kernels per

TABLE 1

Capacity of conducting tissue in the peduncle on main stem of genotypes with the spike fertility genes (values ± standard errors).

Genotype	Peduncle diameter [mm]	Vascular bundles [No.]	Cross section area of vascular bundles [μm²]	Cross section area of phloem [μm²]
1988				
Hana	2.36 ± 0.04	25.6 ± 0.4	349 012 ± 15 634	56 412 ± 2 431
TSS 2	2.99 ± 0.06*	27.6 ± 0.4*	488 298 ± 6 691*	71 789 ± 2 158*
TSS 16	2.98 ± 0.05*	31.4 ± 0.7*	528 003 ± 30 092*	80 444 ± 4 501*
IRS 20	1.92 ± 0.04*	24.5 ± 0.5	346 422 ± 17 889	64 830 ± 5 543
IRS 21	1.96 ± 0.04*	22.0 ± 0.7*	342 752 ± 17 053	59 808 ± 6 485
NS 24	2.52 ± 0.06*	28.2 ± 0.8*	388 033 ± 20 488*	72 737 ± 4 589*
1989				
Hana	2.51 ± 0.06	28.5 ± 0.5	388 395 ± 13 878	70 969 ± 2 312
TSS 2	3.17 ± 0.08*	31.2 ± 0.6*	511 331 ± 16 583*	83 243 ± 3 886*
TSS 16	3.05 ± 0.09*	30.0 ± 0.6*	490 325 ± 23 664*	81 760 ± 3 943*
TSS 37	3.07 ± 0.09*	32.2 ± 1.1*	600 164 ± 32 305*	89 073 ± 5 683*
IRS 20	1.63 ± 0.04*	22.3 ± 0.5*	270 776 ± 14 311*	53 768 ± 2 931*
IRS 21	1.74 ± 0.02*	24.5 ± 0.6*	319 852 ± 16 060*	55 795 ± 2 717*
NS 45	3.29 ± 0.08*	35.8 ± 0.9*	580 092 ± 18 293*	98 187 ± 4 828*
NS 46	2.86 ± 0.06*	31.7 ± 0.4*	459 600 ± 18 099*	88 265 ± 3 504*

* denotes statistically significant difference with regard to the control genotype Hana.

ear and per spikelet. As secondary spikelets have been considered those attached besides the main spikelet on the same spike rachis node. *t*-test has been used for the evaluation of statistically significant difference between the control cultivar Hana and each of the tested genotypes.

RESULTS

There was a difference in the peduncle diameter among genotypes (Table 1). The TSS and NS genotypes had significantly larger peduncle diameter when compared with the control cultivar. The smallest diameter was found to be in genotypes of the IRS type. Similarly, the number of vascular bundles and both phloem and bundle cross section area were highest in genotypes with ears of the TSS and NS types. When compared with the control cultivar the phloem cross section area was higher in 1988 (1989) by 27 to 43 (15 to 26) % and by 29 (24 to 38) % in genotypes of TSS and NS groups, respectively. Only in genotypes of the IRS type, the anatomical parameters were similar (in 1988) or even smaller (1989) than those of the control cultivar Hana (Fig. 1).

The genotypes significantly differ in their number of spikelets per spike (Table 2). The highest spikelet number per spike was found in cultivars of the

TSS type, where the number of main (primary) spikelets was similar to that of the control cultivar. However, TSS genotypes produce additional (sessile, secondary) spikelets thus reaching a significantly higher total number of spikelets per spike. Hence, an increase in spikelet number in this type is not related with an increase in a number of spike rachis internodes. Although there has been a smaller number of kernels per spikelet in these cultivars, their total number of kernels per ear overranged the cultivar Hana. It was higher than the control by 37 to 46 and by 13 to 30 % in 1988 and 1989, respectively (Fig. 1).

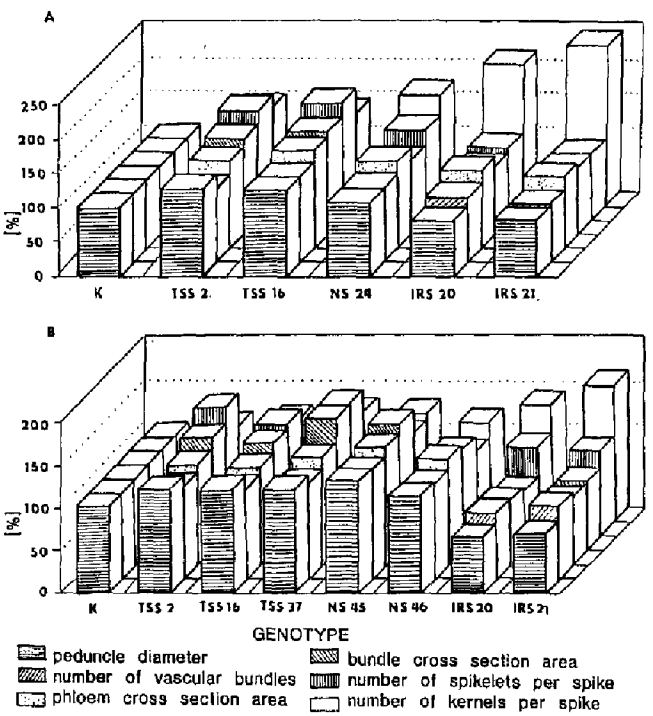

Fig. 1. Relative values characterizing peduncle anatomy and elements of ear productivity on the main stem of winter wheat genotypes with spike fertility genes inducing the TSS, NS and IRS types of the ear. The samples were harvested from field grown plants in 1988 (Fig. 1A) and 1989 (Fig. 1B). Data of the control variety Hana taken as 100 percent.

The highest number of kernels per ear was found in genotypes with the branched spikes, *i.e.* in the IRS type. Their number of kernels per spike was higher by 109 to 139 % and by 38 to 62 % in 1988 and 1989, respectively. As a typical feature of these genotypes was there a very high number of kernels per spikelet due to the presence of 7 to 12 longer spikelets. The number of developed kernels in them varied from 4 to 14.

DISCUSSION

The number of vascular bundles as well as phloem and bundle areas in peduncle cross section were directly proportional to the peduncle diameter giving calculated correlation coefficients of 0.918, 0.899 and 0.941, respectively. This relationship is likely to be general because also Pushkarenko (1984) deduced a similar conclusion from his data on genetically different samples of wheat. In 1988, the highest stem diameter was found in genotypes of the TSS ear type. They differed from the control by 23, 51 and 43 % for the bundle number, bundle and phloem areas, respectively. In 1989, the highest values were measured in the NS genotypes giving values higher than the control by 26, 49 and 38 percent for bundle number, bundle and phloem area. The TSS and NS genotypes had both a higher conducting capacity and a higher kernel number per ear. A similar relationship indicating a positive correlation between the stem diameter and number of kernels per ear was also described by Hamid and Grafius (1978) on barley.

From all the investigated genotypes the highest number of kernels per spike was determined in the IRS type. However, the values of their anatomical characteristics were equal or even significantly lower than those of the cultivar Hana. Such a finding substantially differs from the conclusion by Evans *et al.*

TABLE 2

The ear structure parameters of the main stem of genotypes with spike fertility genes (values ± standard errors).

Genotype	Number of spikelets			Number of kernels per	
	Main	Secondary	Total	spikelet	spike
1988					
Hana	17.7	–	17.7 ± 0.3	2.56 ± 0.06	44.8 ± 1.3
TSS 2	18.6	10.0	28.6 ± 0.5*	2.28 ± 0.05*	65.2 ± 2.4*
TSS 16	18.2	12.6	30.8 ± 1.1*	1.99 ± 0.04*	61.4 ± 2.3*
IRS 20	19.0	–	19.0 ± 0.5*	4.92 ± 0.22*	93.8 ± 5.2*
IRS 21	17.6	–	17.6 ± 0.9	6.04 ± 0.17*	107.2 ± 7.7*
NS 24	23.8	–	23.8 ± 0.4*	3.07 ± 0.05*	73.4 ± 2.0*
1989					
Hana	20.8	–	20.8 ± 0.5	2.46 ± 0.06	51.5 ± 2.1
TSS 2	21.3	9.8	31.1 ± 1.1*	1.88 ± 0.09*	58.3 ± 3.5*
TSS 16	21.8	5.8	27.6 ± 1.1*	2.31 ± 0.10	62.8 ± 1.5*
TSS 37	24.5	7.7	32.2 ± 0.8*	2.07 ± 0.07*	66.9 ± 3.2*
IRS 20	21.9	–	21.9 ± 0.4	3.26 ± 0.08*	71.3 ± 1.7*
IRS 21	21.1	–	21.1 ± 3.6	3.94 ± 0.16*	83.3 ± 4.7*
NS 45	25.1	–	25.1 ± 0.4*	2.75 ± 0.14	66.6 ± 2.5*
NS 46	20.7	–	20.7 ± 0.3	2.93 ± 0.08*	60.4 ± 1.9*

* denotes statistically significant difference with regard to the control genotype Hana.

(1970) who described an increase in the phloem cross section area in peduncle during wheat evolution as brought about by an increased demand of the ear for higher assimilate supply. It seems fully justified to assume that conclusion by Evans *et al.* (1970) as deduced from measurements on di-, tetra- and hexaploid wheat forms need not be directly applicable to genotypes with such a different spike types as used in our experiments.

From all the investigated genotypes, the highest number of kernels per spike was determined in the IRS type. This high number was due to the extremely high number of kernels developed in the prolonged spikelets. This phenomenon is geneticaly determined by the very high number of initiated florets in these spikelets although higher reduction of florets might subsequently occur in the IRS spikes compared with the reduction in the standard genotypes during the period before and shortly after anthesis (Kadkol and Halloran 1988).

The competition for assimilates between the stem and the ear is likely to be one of the reasons for floret sterility (Brosting and Kirby 1991). The shortage of assimilates in the developing ear could negatively influence the floret growth and embryo formation especially in the long stem genotypes in which the peduncle growth continues well after anthesis (Wardlaw 1970). In our experiments, the lower translocation capacity could also induce an insuficient supply of the ear with assimilates and consequently an increased rate of floret reduction in the long IRS genotypes.

Up to now, the knowledge of genotypes with fertility genes has been very limited. Further studies are needed in developmental anatomy of spikes and stems to elucidate also differences in the relationships between the conducting capacity and kernel number per spikes in the TSS, NS and IRS genotypes.

REFERENCES

Brandle, J. E., Knott, D. R.: The effect of a gene for semidwarfism (Rht 1) on various characters in a spring wheat cross. – Can. J. Plant Sci. **66** : 529–533, 1986.

Brooking, I. R., Kirby, E. J. M.: Interrelationships between stem and ear development in winter wheat: the effects of a Norin 10 dwarfing gene, Gai/Rht 2. – J. agr. Sci. **97** : 378–381, 1981.

Evans, L. T., Dunstone, R. L., Rawson, H. M., Williams, R. F.: The phloem of the wheat stem in relation to requirements for assimilate by the ear. – Aust. J. biol. Sci. **23** : 743–752, 1970.

Hamid, Z. A., Grafius, J. E.: Developmental allometry and its implication to grain yield in barley. – Crop Sci. **18** : 83–86, 1978.

Housley, T. L., Peterson, D. M.: Oat stem vascular size in relation to kernel number and weight. I. Controlled environment. – Crop Sci. **22** : 259–263, 1982.

Kadkol, G. P., Halloran, G. M.: Development and floret survival in wheat ears with supernumerary spikelets. – Ann. Bot. **62** : 559–568, 1988.

Lupton, F. G. M.: Further experiments on photosynthesis and translocation in wheat. – Ann. appl. Biol. **71** : 69–79, 1972.

Nátrová, Z.: [Conducting capacity in the peduncle of winter wheat varieties differing in their ear productivity.] In Czech. – Rost. Výroba **33** : 1085–1091, 1987.

Pennel, L., Halloran, G. M.: Influence of vernalization and photoperiod on supernumerary spikelet expression in wheat. – Ann. Bot. **53** : 821–831, 1984.

Pushkarenko, A. Ya.: [Structural pattern of vascular system in the peduncle of various winter wheat varieties.] In Russ. – In: Sb. nauch. Tr. vsesoyuz. selskokhoz. gos. Inst. Odessa. Pp. 45–50. 1984.

Smoček, J.: [Phenocopies of gene spike fertility in wheat.] In Czech. – Rost. Výroba **33** : 529–537, 1987.

Wardlaw, I. F.: The early stages of grain development in wheat: Response to light and temperature in a single variety. – Aust. J. biol. Sci. **23** : 765–774, 1970.

Vorst, J. J. (ed.): Experiments in Crop Science. Crop Science Society of America, Inc. Madison, 1990. 62 pp.

The purpose of this publication was to prepare and provide a series of crop science experiments for use in junior high school biology or science classes. These fundamental experiments can help teachers to explain basic biological processes via demonstration and laboratory experiments to students. The whole series is intendent to provide students deeper information, involve them in learning process and motivate them to study and retain more.

Experiments in this publication represent basic plant biology applications to crop growth, development and production, having the nature of a law. They are intended to show interesting examples how crop science knowledge directly affects plant production.

Each experiment is individual and consist of two parts: a Student's Guide and a Teacher's Guide which help students to understand, and carry out the apropriate experiment. Student's Guide includes introduction, objective, procedure, questions and references. In Teacher's Guide one can find more detailed objectives, materials and equipment, procedure, experiments, discussion and mostly also evaluation.

The publication comprises the following experiments: Plant tissue and cell culture, Plant genetics, Germination and seedling growth under water stress, Nutrient deficiences in plants, Nitrogen fixation and legume inoculation, Germination and vigor of seeds, Seed viability, Plant growth regulation.

All of experiments demonstrate basic plant biology applied in plant reproduction and growing. Listed texts are suitable for use in Grammar or alternatively in Secondary Schools where stress is put on agriculture. For use in European High Schools it would be better to write everything in a more detailed way, add more difficult and exacting procedures and provide more suitable pictures. From educational viewpoint this booklet is well itemized and can be used as an introductory publication for crop science problems.

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